NATIONAL VEGETATION MAPPING FOR FIRE APPLICATIONS

Donald O. Ohlen
USGS EROS Data Center
Sioux Falls, SD 57198
Phone: (605)594-6026
E-mail: ohlen@edcmail.cr.usgs.gov

Don G. Despain
USGS, MESC, Greater Yellowstone Field Station
Montana State University
Bozeman, MT 59717-3460
Phone: (406) 994-7257
E-mail: ddespain@montana.edu

Robert E. Burgan
USDA Forest Service
Rocky Mountain Research Station
Intermountain Fire Sciences Laboratory
PO Box 8089
Missoula, MT 59807
Phone: (406) 329-4864
E-mail: firebug@centric.net

ABSTRACT

Fuels maps are a fundamental part of fire management activities such as prescribed fire planning, suppression strategies, smoke management, and fire effects. The constraints imposed by fiscal and human resources make it desirable to have a method that can rapidly and objectively map fuels over very large areas. The Multi-Resolution Land Characteristics Interagency Consortium personnel are producing a 30 meter resolution land cover data set for the conterminous U. S., based on a mosaics of Landsat Thematic Mapper (TM) images of both leaf-on and leaf-off periods. This spatially consistent mapping of the U. S. produces land cover classes that are too broad for any fire fuels mapping effort. The data set does, however, provide a mapping base upon which further land cover definition may be derived. A demonstration centered on the Big Horn Mountains of Wyoming, was produced with an unsupervised clustering of the original TM data to create subclass segmentation of representative original land cover classes. The mapping process demonstrated a simple, repeatable, and extendable methodology for extracting subclass spatial patterns of similar vegetation from a National Land Cover Data set.

Keywords: land cover, fire fuels, mapping, remote sensing, Landsat

INTRODUCTION

Modern computational capabilities enable sophisticated implementation of fire behavior and effects algorithms for assessing probable fire intensity and effects across broad landscapes. Unfortunately, basic data required to drive realistic simulations are difficult and expensive to obtain: thus, are generally lacking for spatially significant areas. For example, the Fire Area Simulator (FARSITE) (Finney, M. A. 1998) requires eight digital data layers to generate realistic fire behavior simulations, including elevation, aspect, slope, fuel model, canopy cover, crown height, crown base height, and crown bulk density. If fire effects (Reinhardt, E. D. et al. 1997) are to be estimated, tree species, diameter, height and crown ratio are also required. Fuel consumption and smoke emission models require data on live and dead fuel loads. The National Fire Danger Rating System (Deeming, J. E. et al. 1977) utilizes yet another set of vegetation/fuel characterizations. Thus, data collected for use in one system are not necessarily applicable in another.

Various vegetation/fuel mapping efforts have been completed. At a coarse scale, a 1km resolution national fire danger rating fuel model map has been prepared for the conterminous United States (Burgan, R. E. et al. 1998) from a land cover characteristics database of the U. S. (Loveland, T. R. et al. 1991). This land cover database was developed from remotely sensed data originally collected in 1990 by the U. S. Geological Survey. While this vegetation/fuel map is very useful for fire danger rating purposes, it does not provide enough detail for site specific fire management problems, and the fuel models it represents are not applicable to the fire behavior processor.

Remote sensing data are one of the most extensive sources of information for applications of vegetation mapping. Although these data may not be considered the ‘perfect’ data source, they do however, provide characteristics that warrant the development of methodologies for vegetation/fuel mapping efforts. These data provide broad continuous coverage, especially in comparison to ‘ground data,’ and are relatively cost effective for large area mapping. The continuous spatial coverage that remotely sensed data provide, is significant in that interpretations from these data span administrative or ecological boundaries. Remote sensing technology has provided data since the early 1970’s, and current space programs provide for continuous coverage well into the future. These data are important not only for initial vegetation mapping efforts, but also have value in monitoring vegetation change over time.

Keane and others (1998) have used a combination of biophysical modeling and remote sensing data interpretations to create FARSITE input data layers for over 5 million hectares on five land areas within the Rocky Mountains — the Beaverhead-Deerlodge and Gallatin forests in Montana, the Salmon-Challis forest in Idaho, the Selway-Bitterroot Wilderness in Montana and Idaho, and Gila forest in New Mexico. The mapping strategy that Keane and others used was based on the assumption that fuels maps can be created from three base layers — biophysical setting, cover type, and structural stage. They state that; “the biophysical layer describes the long-term environmental conditions across the landscape, such as weather, soils, topography, that dictate ecosystem properties and dynamics.” Cover type describes the most common plant species, and structural stage describes surface and aerial fuel characteristics and the potential for crown fire (Finney, M.A. 1995). Many other mapping methodologies are possible, but the point is that land management agencies need a standard method to create vegetation maps that are useful for all phases of fire management.

Toward this end, Sandberg and others (unpublished briefing paper) are in the process of “designing a National Fuels Characterization system, based on the rapidly expanding use of Fuel Characteristics Classes for hazard appraisal and mapping, that will (1) provide a range and distribution of realistic values based on field data for each fuel property and element; (2) provide the precision commensurate with fuels management decisions; and (3) enable the modeling of transitions over time from one class to another.” The objective of Sandberg’s effort is to provide a nationally consistent design for a fuels database that will provide fuels inputs to the various systems designed for fire management applications. A fuel characteristics class is defined by Sandberg and others (unpublished briefing paper) as “a stylized fuelbed derived from remotely sensed, modeled, or measured data, that can be used to drive fire behavior and effects models.’’ In essence, it will be a nationally consistent library of data about numerous vegetation types, from which each fire management analysis system can obtain required information. This plan, however, begs for a nationally consistent land cover map, rather than the project or national forest size efforts that have been the norm. Such efforts can be very useful for specific areas, but become very difficult to mosaic into a consistent whole because of the disparity of methods and mapping categories applied.

Much work has been completed over the last several decades by a variety of agencies that have produced reliable intermediate-scale land cover information from remotely sensed data. The applications of these data have been as varied as the agencies producing the data; examples of uses include hydrologic studies of runoff (Leahy, P. P. et al. 1993), environmental modeling (Frohn, R. C. 1998), and biodiversity studies (Scott, J. M. et al. 1996). Generally, the spatial extent of these mapping efforts has been at a state, national forest or smaller local level and they hold little application value for any collective ingest into a national land cover assessment study. These numerous disparate land cover data sets are lacking in a consistent land cover legend, use various sensor data, consist of varying dates of source data, lack standard processing methodologies, lack total national coverage and therefore have little use in national applications. The only available national, intermediate-scale, land cover data set has been the land use/land cover (LUDA) data set produced by the U. S. Geological Survey. This data set was derived from high altitude aerial photography acquired in the 1970’s and therefore does not reflect recent conditions.

Substantial obstacles impede any efforts to use satellite data in developing a standardized land cover mapping data set at a national level. For example, to map the conterminous U. S. with Landsat satellite data at a 30 meter resolution, computer processing capabilities would be required for about 12 gigabytes of data per data layer. Inclusion of multispectral images, temporal data, and ancillary data sets when producing land cover data can produce a data volume tenfold the original size. Therefore, it seems imperative that some effort needs to be spent developing methodologies that utilize existing data sets.

NATIONAL LAND COVER DATA

The National Land Cover Data (NLCD) project underway as part of the Multi-Resolution Land Characteristics (MRLC) Interagency Consortium (Vogelmann, J. E. et al. 1998) provides a unique opportunity to utilize a spatially consistent mapping of the vegetation of the United States. The NLCD effort will produce an intermediate scale land cover data set for the conterminous United States. The main objective of the project is to develop a generalized, consistent, seamless, and reasonably accurate land cover data set that is appropriate for a wide variety of uses. This mapping effort has resulted in the collection of approximately 410 plus Landsat Thematic Mapper (TM) data path-row acquisitions covering the United States for 1991, 1992, 1993. The TM data sets have been radiometrically corrected, terrain corrected using 3-arc-second digital terrain elevation data (DTED), and georegistered using ground control points resulting in a root mean square error of less than 1 pixel (30m). This data set includes not only leaf-on and leaf-off TM data, but DTED, slope, aspect, shaded relief, population density, LUDA, national wetlands inventory, and political boundary data.

Procedures to effectively process this large data volume have been incorporated into this effort. The mapping is being conducted on a region-by-region basis using the EPA Federal Regions. Larger federal regions are divided into subregions, keeping the data set size within a software limitation of 2 gigabytes. This equates to approximately 700,000 square kilometers per subregion. Edge matching is done between each subregion and each federal region. This assures a consistent and seamless land cover product for the conterminous United States.

Processing of the data includes (1) the generation of leaf-on and leaf-off TM mosaics for a region, (2) clustering using an unsupervised clustering algorithm, (3) interpreting and labeling the clusters using aerial photographs as reference data, (4) modeling with the ancillary data to resolve mixed clusters, and (5) onscreen digitizing to further refine the basic classification. The NLCD classification is a hierarchical system consisting of 21 classes of land cover (Table 1). The intent of this hierarchical protocol is to provide a structure that easily links existing generalized land cover data sets with the more detailed natural vegetation data.

Water
- 11 Open Water
- 12 Perennial Ice/Snow

Developed
- 21 Low Intensity Residential
- 22 High Intensity Residential
- 22 Commercial/Industrial/Transportation

Barren
- 31 Bare Rock/Sand/Clay
- 32 Quarries/Strip Mines/Gravel Pits
- 33 Transitional

Forested Upland
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest

Shrubland
- 51 Shrubland

Non-natural Woody
- 61 Orchards, Vineyards, Other

Herbaceous Upland
- 71 Grasslands/ Herbaceous

Herbaceous Planted/Cultivated
- 81 Pasture/Hay
- 82 Row Crops
- 83 Small Grains
- 84 Fallow
- 85 Urban/Recreational Grasses

Wetlands
- 91 Woody Wetlands
- 92 Emergent Herbaceous Wetlands

Table 1. National Land Cover Data classification system.

The land-cover classes defined for this map are rather broad; describing general forest, shrub, grass, barren, and urban categories. While these classes are sufficient for the MRLC Consortium's use, they are too broad for use by fire managers. However, it is quite feasible to use clustering algorithms to further subdivide these broad land cover classes into a sufficient number of subclasses that can be useful to fire managers. The resulting map does not identify vegetation by species, but rather defines areas likely to have similar vegetation characteristics. Field personnel then need to provide the label for the subclasses of each general vegetation type, perhaps combining or splitting some of the subclasses in the process. The resulting map then becomes a nationally consistent key to defining the geographical extent of data collected for the National Fuels Characterization System.

This paper presents a fledgling effort to map polygons of similar vegetation for the Big Horn Mountains of Wyoming. The intent of this effort was to illustrate a process whereby NLCD could be used to spatially define areas of similar vegetation characteristics.

VEGETATION CHARACTERISTICS OF THE BIG HORN MOUNTAINS

The Big Horn Mountains lie along the boundary between Montana and Wyoming in a northwest to southeast direction, mostly between 43º and 45º N and 107º and 108º W. The mountains were created by the uplift of three major basement blocks, with the center block raised higher than the other two. This created a central core of granite surrounded by sedimentary rocks. The base of the range is about 5,000 ft. (1500 m) on both the east and west flank, and the highest point is Cloud Peak at 13,175 ft. (4016 m). The major vegetation pattern of the range is strongly influenced by the pattern of exposed bedrock and climate created by changes in elevation (Despain, D. G. 1973). Areas underlain by shales and flat lying limestone are covered with grasslands. Lodgepole pine (*Pinus contorta* Dougl.) dominates most of the granite, but at the highest elevations where spruce (*Picea engelmannii* Parry) and fir (*Abies lasiocarpa* (Hook.) Nutt.) dominate. Limestones on steep slopes are generally covered with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.) and ponderosa pine (*Pinus ponderosa* Laws.) forests at the lower elevations, while spruce and fir dominate the upper elevations. Flat lying limestone is usually covered with grasslands.

Mean annual precipitation at the base of the mountains varies from 13 in (350 mm) to 20 in (500 mm), south to north along the east side and varies from 4.5 in (125 mm) to 10 in (250 mm), south to north along the west side. At 8000 ft. (2440 m) mean annual precipitation is about 530 mm. Peak mean monthly precipitation occurs in April, May, and June across all elevations.

Upper timberline is close to 10,000 ft. (3050 m). Lower timberline is near 5000-6000 ft. (1500-1800 m) on the east side and 7000 ft. (2100 m) on the west side with a juniper zone extending down to about 5000 ft. (1500 m).

The non-agricultural vegetation between the upper and lower timberline is either sagebrush (*Artemisia tridentata* Nutt.) shrublands with an Idaho fescue (*Festuce idahoensis* Elmer) understory or grasslands dominated by Idaho fescue. On the east side, the low elevations are covered mostly by grasslands dominated by bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Schribn. & Smith), little bluestem (*Andropogon scoparius* Michx.), and junegrass (*Koeleria cristata* Pers.) with similar grasslands continuing on to the east. Juniper woodlands are absent from the east side. Wheatgrass also dominates the lower elevation grasslands on the west side, but sagebrush forms an overstory across much of the area. Juniper (*Juniperus osteosperma* (Torr.) Little) forms a woodland over extensive areas. At lower elevations these types border on semiarid shrublands and Great Basin Desert vegetation. Higher elevation grasslands are dominated by Idaho fescue. Sagebrush also covers extensive areas, reaching nearly to upper timberline.

Forests cover about 60% of the area between lower and upper timberline, with more than half dominated by lodgepole pine. Ponderosa pine forests are the lowest elevation forests. They are distributed along the entire east side and the southern quarter of the west side. The dry sites usually have an understory of ponderosa pine, while cooler, moist sites have an understory of Douglas-fir. A shrub layer with various combinations of ninebark (*Physocarpus monogynus* (Torr.) Coult.), snowberry (*Symphoricarpos albus* (L.) Blake), common juniper (*Juniperus communis* (L.)) and buffaloberry (*Shepherdia canadensis* (L.) Nutt.)may be present. Bluebunch wheatgrass is a common herbaceous component. Douglas-fir forests form a band between ponderosa pine stands below and lodgepole pine or spruce-fir stands above. On the northern three fourths of the west side, Douglas-fir stands are the lowest forest vegetation. In the lower part of this zone the understory is composed of seedlings of Douglas-fir, but in the upper part spruce and fir seedlings form an understory. Common juniper or wild currents (*Ribes* (L.)) comprise a sparse shrub layer, usually covering only one percent of the forest floor. Lodgepole pine forests are strongly associated with the granitic core but also occur as early successional stages on other substrates. Young stands are usually very dense, with little understory and very little surface fuel. Older stands on the sedimentary rocks may have an understory of spruce and fir but on the granites the understory is largely lodgepole pine. In dense stands the forest floor is covered with dead needles and little else. In the more open stands a dense cover of grouse whortleberry (*Vaccinium scoparium* Leiberg) is more common.

SEGMENTATION OF NLCD CLASSES

Procedures used for defining a segmentation process of the NLCD classes for the Big Horn Mountains must be applicable across all federal regions. These procedures have to be simple, repeatable, and extendable across large geographical regions. Each region will require some level of characterization with ancillary data sets that help identify the uniqueness of each cover class subdivision. Therefore, this process will need to permit the incorporation of attributes of regional or thematic significance. The resulting segmentation of the NLCD classes will provide spatial definition to the variability within cover classes.

The evergreen forest and grassland cover classes, the two dominant cover classes within the Big Horn Mountains (Figure 1), were selected to illustrate one possible segmentation process. These two land cover classes were processed separately to maintain control on the number of subclasses identified within each cover class. Evergreen forests, having more variability in fire fuel characteristics than grassland cover, requires more subclasses. The two cover classes were used to mask the NLCD leaf-on Landsat data into two images. The two images then become the source data for the segmentation process. The data sets were processed through an unsupervised ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering process, selected for its simplicity and efficiency in application across broad regions. The ISODATA clustering method uses the minimum spectral distance formula to form the clusters.

The evergreen data set was partitioned into fourteen clusters and the grassland data set into ten clusters. The number of clusters selected was arbitrary and could vary by region or could be adjusted if a ‘good fit’ was not achieved. Clusters for both cover types were combined into a single data set of twenty-four new subclasses, as represented in Figure 2, which were then combined with the MRLC ancillary data layers for the Big Horns. Ancillary data layer statistical summaries were generated for each subclass. These summaries are useful in characterizing the subclasses to assign a meaningful label.

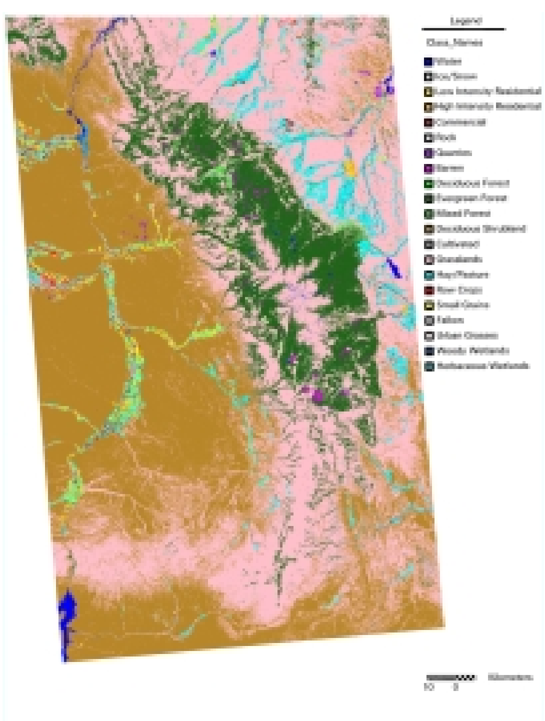

Figure 1. NLCD classification for the Big Horn Mountains.

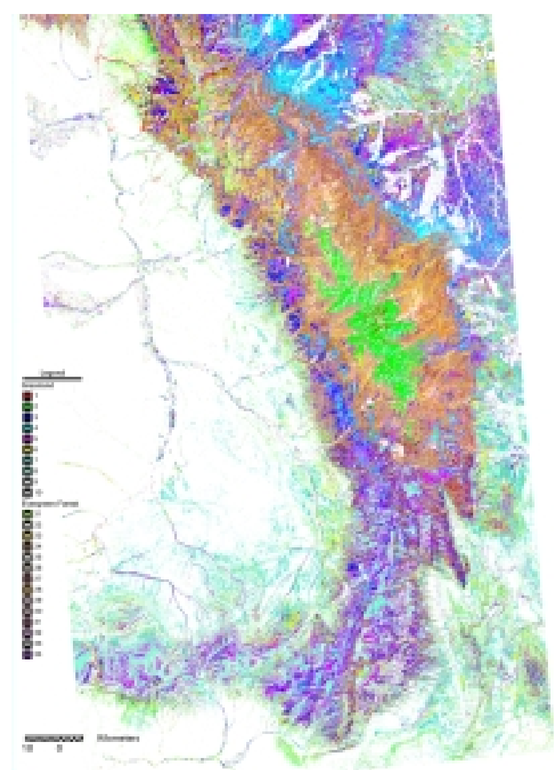

Figure 2. Reclustered data of the MRLC grassland and evergreen land cover classes.

As expected, the grassland subclasses appear to be more spatially distinct than the evergreen subclasses. These grassland subclasses tend to show a pattern of grassland northwest of the Big Horns different from the grassland to the southwest of the Big Horns. This agrees with the precipitation pattern described earlier, where more moisture occurs to the northeast and drier conditions occur to the southwest. Grassland above timberline tends to separate from the other subclasses as well, providing an elevation break in the classification. The conifer classes, as expected, appear much more complicated. Four subclasses account for just over 50 percent of the conifer class (these are class numbers 6, 7, 8, and 9 in Table 2) and tend to be associated with the defined lodgepole pine boundaries of the Big Horns. These four subclasses occur on gentler slopes and have a preference for the northeast to southeast aspect. Conifer subclasses identified as 1, 2, and 3 in Table 2 favor northwest facing slopes. Subclass 1 spatially occurs in the northern third of this mountain range, favoring the lower elevations with steep slopes, while subclass two tends to occur at the higher elevations. These observations illustrate that, within the NLCD classes, segmentation processes can be used to help define spatial patterns of similar vegetation. However, the spatial patterns defined by this process do not identify fuels classes but rather provide a map base from which fuel characterization may be defined. The mapped vegetation need biophysical definition to provide input to any fuel characteristics class.

SUMMARY

If the future of fire management is in the incorporation of a standardized National Fuels Characterization System, then a standard methodology to complete vegetation maps is needed. The NLCD data set is one existing national data set that can provide a base for this standard mapping methodology. This validated data set provides a consistent, seamless, land cover product for the conterminous United States. Access to the NLCD source data and the ancillary data layers provide the tools required to identify and characterize subclass regions within NLCD classes. The process used here to define the subclasses was simple and could be repeated for larger geographical regions.

The MRLC program is a continuing supported effort that will be remapping the United States under the developing NLCD 2000 project. This project, similar to the NLCD project, will remap the United States using data acquired from the recently successfully launched Landsat 7 ETM sensor. NLCD 2000 is proposed to expand the mapping to include Alaska and the source data will include three acquisitions dates for each path-row. This data set will become a valuable product for updating any National Fuels Characterization system.

Evergreen Subclass #	% of Evergreen	Elevation			Slope			Aspect		
		Mean	Std	Mode	Mean	Std	Mode	Mean	Std	Mode
1	2	2145	339	2182	55	23	61	264	112	330
2	5	2644	375	2852	28	22	16	211	134	347
3	8	2438	311	2585	35	21	22	247	122	334
4	10	2329	313	2512	32	20	18	203	132	5
5	5	2085	372	2058	34	19	25	157	121	44
6	17	2509	261	2511	20	15	11	173	118	24
7	11	2356	320	2387	24	17	14	157	99	83
8	10	2492	350	2403	21	16	11	169	102	91
9	10	2346	433	2572	25	19	13	169	96	122
10	3	2595	559	3010	26	20	16	197	123	361
11	5	1915	445	1462	29	19	19	179	115	0
12	5	2510	546	3006	24	18	14	177	101	361
13	6	2092	484	2401	26	19	14	175	102	99
14	2	2166	525	2524	28	22	13	162	89	148

Table 2. Digital Elevation Model data characteristics for the evergreen subclasses.

REFERENCES

Burgan, R. E., Klaver, R. W., and Klaver, J. M. (1998). Fuel models and fire potential from satellite and surface observations. *International Journal Wildland Fire*, 8(3):pp. 159-170.

Deeming, J. E., Burgan, R. E., and Cohen, J. D. (1977). The National Fire-Danger Rating System – 1978. USDA Forest Service General Technical Report INT-39, U. S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.

Despain, D. G. (1973). Vegetation of the Bighorn Mountains, Wyoming, in relation to substrate and climate. *Ecological Monographs*, 43:pp. 329-355.

Finney, M. A. (1998). Fire Area Simulator - model development and evaluation. Research Paper RMRS-RP-4, U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Finney, M. A. (1995). FARSITE Fire Area Simulator version 1.0 User guide and technical documentation. Systems for Environmental Management Report, Systems for Environmental Management, Missoula, MT.

Frohn, R. C. (1998). *Remote Sensing for Landscape Ecology- New Metric Indicators for Monitoring, Modeling, and Assessment for Ecosystems*, Lewis Publishers, Boca Raton, FL.

Keane, R. E., Long, D. G., Schmidt, K. M., Mincemoyer, S. and Garner, J. L. (1998). Mapping fuels for spatial fire simulations using remote sensing and biophysical modeling. In: J. D. Greer, editor, *Proceedings of the Seventh Forest Service Remote Sensing Applications Conference*. Nassau Bay, TX. American Society for Photogrammetry and Remote Sensing, Bethesda, MD, pp. 301-316.

Leahy, P. P., Ryan, B. J., and Johnson, A. (1993). An introduction to the U. S. Geological Survey's National Water-Quality Assessment Program. *Water Resources Bulletin*, 29: pp. 529-532.

Loveland, T., Merchant, J. W., Ohlen, D. O., and Brown J. F. (1991). Development of a land-cover characteristics database for the conterminous U. S. *Photogrammetric Engineering and Remote Sensing*, 57(11):pp. 1453-1463.

Reinhardt, E. D., Keane, R. E., and Brown, J. K. (1997). First Order Fire Effects Model: FOFEM 4.0 user's guide. USDA Forest Service General Technical Report INT-GTR-344, U. S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.

Scott, J. M., Tear, T. H., and Davis, F. W. (1996). *Gap Analysis. A Landscape Approach to Biodiversity Planning*, American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

Vogelmann, J. E., Sohl, T. L., Campbell, P. V., and Shaw, D. M. (1998). Regional land cover characterization using Landsat Thematic Mapper data and ancillary data sources. *Environmental Monitoring and Assessment,* 51:pp. 415-428.